LYSIMETRIC ESTIMATION OF CROP WATER USE OF TOMATO

(*LYCOPERSION ESCULENTUM L.C.V.TRISTAR*).

BY

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MATRIC No. 2005/23549EA

DEPARTMENT OF AGRICULTURAL AND BIORESOURCES ENGINEERING

FEDERAL UNIVERSITY OF TECHNOLOGY MINNA, NIGER STATE NIGERIA.

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FEBRUARY, 2012.

DECLARATION

I hereby declare that this thesis is a record of a research work that was undertaken and written by me. It has not been presented prior to this moment for any degree, diploma or certificate at any university or institution to the best of my knowledge. Information derived from published and printed source were duly referenced in the text and the work is free from plagiarism.

AL-MUSTAPHA ALIYU		06/03/2012
2005/23549EA	Signature	Date

CERTIFICATION

This is to certify that the project entitled "Lysimetric estimation of crop water use of tomato (*Lycopersion esculentum l.c.v. tristar), using Micro-weighing lysimeter*" by Al-mustapha Aliyu, meets the regulations governing the award of the degree of Bachelor of Engineering (B.Eng.) of the Federal University of Technology, Minna, and it is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION

work is dedicated to GOD almighty ALLAH that has called and chosen me. Also to my mum ladddy HADIZA, ALIYU MUSTAPHA and ALIYU .B. MUSTAPHA who has been my pillar of ort and strength ever since my time of birth and finally to my family members and friends for unending love, support, appreciation, joy and understanding throughout the period of my stay in niversity.

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ABSTRACT

\ total of three Micro-weighing lysimeters were used to estimate the crop water use of tomato *Lycopersion esculentum*). An empirical formula was used to estimate the reference ›vapotranspiration (ETo) using the climatic data of the study area. The field trial was carried out luring the 2011 rainy season at the experimental field of the Department of Agricultural and 3io-resources Engineering, Federal University of Technology, Minna permanent site. The daily lisplacement of water in the flexible tube due to change in weight as water enters or leaves the ysimeter tanks were translated to crop water use. The crop water use estimated using the ysimeter were compared with estimates based on weather data-reference evapotranspiration. The results showed that the daily water use of the tomato crop from the lysimeters at the three growth stages (initial, mid-season and maturity) were 31.76mm/day, 23.84mm/day and ?5.85mm/day, respectively and the corresponding reference evapotranspiration values were).015mm/day, 0.012mm/day and 0.013mm/day, respectively. This implies that the weighing nicro-lysimeter technique and the Hargreaves FAO-56 method have thus offered an easier and :heaper opportunity to estimate crop water use and other components of the soil water balance ınder rainfall condition. Growers need accurate and timely information on crop water equirement to provide best level of production.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Nigeria has been endowed with abundant water resources. These comprise of major rivers namely Niger, Benue and Cross River and streams with many fresh waters; its annual rainfall along the coast in the Southern-eastern region is about 4000mm while in the Northern–eastern region is 500mm and an average rainfall of 2413mm (Community Portal of Nigeria). However, with population growth rate of 2.38%, inhabitant of 140,003,542 estimation (by National Population Census, July 2006) and blooming economic development, demand for water use is continuously on the increase. Even with vast resources, water is in short supply in Nigeria. Knowledge of crop-water requirement is crucial for water resources management and planning in order to improve water-use efficiency (Hamdy and Lacirignola, 1999; Katerji and R'ana, 2008). The needs for increasing food productivity have become the major concern for Agricultural and Bioresources Engineers. This could be achieved by means of irrigation. The primary reason for irrigating crops is to supplement the natural sources of water, such as rainfall, floods, dew and ground water that seep into root zone of growth. In addition, the supply of water by means of irrigation is a common practice especially in Africa and particularly in arid, semi-arid and Tropical region and also during dry-season where the amount of rainfall intensity cannot satisfy the crops water requirement for effective growth and cooling purposes (Al-Kaisi et al., 2009).

Crop-water requirements vary during the growing period, mainly due to variation in crop canopy and climatic conditions, are related to both cropping technique and irrigation methods. About 99% of the water uptake by plants from soil is lost as evapotranspiration (ET), so, it can be stated that the measurement of actual crop evapotranspiration (ETc) on a daily scale for the whole vegetative cycle is equal to the water requirement of the given crop (Shideed et al., 1995). Evapotranspiration is defined as the water lost as vapour by an unsaturated vegetative surface and it is the sum of evaporation from soil and transpiration by plants. In order to avoid the underestimation or overestimation of crop water consumption, knowledge of the exact water loss through actual evapotranspiration is necessary for sustainable development and environmentally water management in Nigeria. However, overestimation of water consumption is very common practice in some regions, causing both wastes of water and negative impacts on economic, social and environmental levels. Then, a correct knowledge of ETc allows improved water management by changing the volume and frequency of irrigation to meet the crop requirements and to adapt to soil characteristics.ET can be measured or modelled by more or less complex techniques. Usually, for practical purposes at local-field scale the evapotranspiration is estimated by models usable for the same crop in sites at the same region. The most known and used technique to estimate ET is the one based on the ETo approach (Allen et al., 1998) where the ETc is calculated by using standard agro-meteorological variable and a crop- reference evapotranspiration , the reference evapotranspiration (ETo), which should take into account the relationship between atmosphere, crop physiology and agricultural practices.

To develop an effective irrigation management strategy, it is important to estimate crop water use. Knowledge of reference evapotranspiration (ETo) is essential for the estimation of water use. It helps in determining the water requirement of the crops according to their growth stage and environmental factors.

Tomato is one of main vegetable crops grown in Nigeria. Tomato cultivation in Nigeria is carried-out on highly sandy soil, which is characterized by low water holding capacity and organic matter content. However, Tomato is one of the most widely used fruiting vegetable crops required at home as raw food or at food industries to be processed. The high demand for tomato as raw material has made it one of the most important salad crops that need to be available throughout the year.

To achieve the cultivation of tomato both in dry-season and rainy-season, there is a need for determination of crop water use and reference evapotranspiration (ETo) for irrigation planning and scheduling for available water used to irrigate tomato. This can be obtained by the use of a Micro-weighing Lysimeter method among the several methods used for the purpose to know the water use and (ETo) for tomato crop.

1.2 Statement of problem

Grower's lack-adequate information on the crop water use of various plants they grow, which is critical to high yield and quality of the crops they produce. This project is focused on providing crop water requirements for tomatoes, so as to enable farmers gather necessary information on water use requirements and irrigation scheduling to maintain profitable production of the crops.

1.3 Objectives

The specific objectives of the study were to:

i. **Estimate** crop water use rate for tomato (*Lycopersion esculentum L.C.V. Tristar*), using Micro-weighing lysimeter.

ii. Determination of reference evapotranspiration (ETo), using empirical formula and

iii. **compare** the crop water use with that of weather-based crop water requirement

1.4 Justification of the Project

As growth rate of population increase the pressure of survival and the need for additional fruiting vegetable such as tomato have become a necessity, so all-year round cultivation is of vital importance in order to achieve self sustainability, human and industrial requirement of crops. But water stress during critical growth tends to reduce yields and quality of crops. Hence, there is the need to estimates the water requirements of various crops through the use of reliable and valid equipment such as lysimeter. The estimated crop water requirement should be brought to notice of the growers for profitable production.

LIST OF PLATES

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1.5 Scope of Project

In this project, the Lysimeter method were been used to estimate, respectively the crop water use for tomato (*Lycopersion esculentum*), with three Micro-weighing lysimeters (D_1, D_2 and D_3). Also compute the reference evapotranspiration (ETo) values of tomato, using the climatic parameters of the study area.

CHAPTER TWO

2.0 Literature review

Over 300years ago, different experiments on the determination of evapotranspiration rate of crops have been conducted by several researchers. The first lysimeter investigation was started in France in 1688 by De la Hire, mathematician and meteorologist of Louis xii. Used leaden vessels filled with sandy loam soil and found that more water evaporated from lysimeter planted with grass than from those with bare soil. In the same vain with reference to project area, few studies have been carried-out among such studies (Kowal and Kassam 1976) measure the water required of several crops type using a hydraulic weighing lysimeter at Samaru, Zaria, Nigeria.

In a paper presented on evapotranspiration of selected cereals in Niger state at the 21st annual conference of Nigeria society of agricultural engineering, Egharevba and Mohammed (1999) presented the annual water requirements of $2.42x10^3$; $3.214x10^3$; $3.292x10^3$; and $4.002x10^3$; /ha/annum for maize, millet, sorghum and wheat respectively, as computed from modified penman equation based on reference evapotranspiration (ETr). In the past few decades, many researchers have used lysimeter to measure ET directly for many crops or to provide data for reference ET from climatic data (Anadramistakis et al., 2000; Tyagi et al., 2000; Abdelhadi et al., 2000; Abo-Ghobar and Mohammed, 1995) in Saudi Arabia, in their study using weighing lysimeter, reported Kc value of sunflower which were 11.6-74.2% higher than value suggested by FAO.

Extensive work has been done to estimate Kc value in different part of the world, including Saudi Arabia (Kashyap and panda 2001), using weighing lysimeter the Kc value of potatoes were found to be considerably higher than the corresponding FAO recommended values. Nine years ago an experiment was conducted on weighing lysimeter for measurement consumptive use of Amaranthus, Final year project at department of Agricultural Engineering Futminna by George [2002]; where a peak period consumptive use rate of 7.0mm/day was recorded during the dry season. However, a daily peak evapotranspiration rate, compute the potential and crop evapotranspiration rate for tomato, also estimate the crop coefficient compare with FAO standard, where a peak ETc for lysimeter was 24.12mm/day and 6.11mm/day obtained from B.M.N model by Mohammed (2003). In a clearly definition by (Kang et al., 2003 and Allen et al., 1998); Doorenbos and Pruitt (1977) and (kang et al., 2003) emphasized the need to regional Kc for accurate estimation of water use, under a specific climate condition.

In other study in central Saudi Arabia, nine non-weighing reinforced concrete lysimeter were used to grow alfalfa (*Medicago sativa*) as a reference crop, and tomato (*Lycopersion esculentum L.C.V. Tristar*) and squash (*cucurbita pepol*) as and squash at different stages of growth, based on lysimeter measured ET_i and reference alfalfa ET. The estimated values of Kc for tomato at four stages (initial, crop development, reproductive and maturity) were 0.28,0.8,0.96 and 0.75 and the Kc values for tomato was lower than the suggested by FAO for arid areas. Five methods (FAO-penman, Blaney-criddle, Jensen-Haise, pan evaporation and Thornthwaite) were measured by lysimeters and that estimated by the climatological methods, by (Al-Omaran et al., 2004) determine the evapotranspiration of tomato using lysimeter. Also by (Saniay et al., 2007) at Institute of food and agricultural science (IFAS)

University of Florida Immokalae, in Florida, develop monthly Kc value for drip-irrigated water melon grown on the raised beds covered with plastic mulch in South Florida region.

Crop water used is determined either by direct measurement or by calculation from crop and climatic data.

2.1 Evapotranspiration

Evaporation (Ea) and transpiration (T_p) are the two most important processes governing removal of water from the land into the atmosphere. These processes occur simultaneously, and are hard to distinguish from each other (Allen et al., 1998). Stanhill (1973) found considerable interaction between the two processes. The term evapotranspiration (ET) was coined to define the total loss of water from an area. While occurring simultaneously, Ea is governed by the availability of water in the topsoil and the fraction of solar radiations reaching soil surface. Amount of solar radiation reaching soil surface varies with the degree of crop shading. Transpiration (Tp) on the other hand is a function of crop canopy and soil water status. Ea has been found to dominate the ET by as much as 100% during early stages of crop growth while Tp contributes to nearly 90% of the ET for a fully matured crop (Allen et al., 1998). Liu et al. (1998) reported that soil Ea constitutes nearly 30% of the total ETcfor winter wheat.

Reference evapotranspiration (ETo)

ET_o is a representation of the Ea demand of atmosphere, independent of crop growth and management factors (Allen et al., 1998). It can be estimated from the weather data. Allen et al. (1994) define ET_o as "the rate of ET from a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sec/m and an albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, well-watered, and completely shading the ground"... Alternatively ET_o can be estimated from meteorological data using empirical and semi-empirical equations. Numerous empirical methods have been developed to estimate evapotranspiration from different climatic variables. Examples of such methods include Penman-Monteith (Monteith, 1965) and Blaney-Criddle (Blaney and Criddle, 1950). One of the most important factors governing the selection of a method is the data availability. For instance, Blaney-Criddle only requires the temperature data while the Penman-Monteith requires additional parameters such as wind speed, humidity, and solar radiation.. Several studies have been conducted over the years to evaluate the accuracy of different ETo methods. Most of these studies have concluded that Penman-Montieth equation in its different forms provides the best ET_o estimates under most conditions. Therefore, the Food and Agricultural Organization (FAO) recommended FAO-Penman Monteith (FAO-PM) method as the sole standard method for computation of ET_o (Allen et al., 1998). FAO-PM can provide accurate ETo estimates for weekly or even hourly periods.

- **Crop evapotranspiration**

The actual crop water use depends on climatic factors, crop type and crop growth stage. While ETo provides the climatic influence on crop water use, the effect of crop type and management is addressed by ETc. Factors affecting ETc such as ground cover, canopy properties and aerodynamic resistance for a crop are different from the factors affecting reference crop (grass or alfalfa); therefore, ETc differs from ETo.

The characteristics that distinguish field crops from the reference crop are integrated into a crop factor or crop coefficient (Kc) (Allen et al., 1998). Kc is used to determine the actual water use for any crop in conjunction with ET_o.

- **Crop coefficient**

The crop coefficient (Kc) is computed as the ratio of reference and crop ET. Factors affecting Kc include crop type, crop growth stage, climate, soil moisture. Kc is commonly expressed as a function of time. However, Kc as a function of time does not take into account environmental and management factors that influence the rate of canopy development (Grattan et al., 1998). Therefore, most researchers have reported Kc as a function of days after transplanting which helps to reference Kc on crop development stage (Allen et al., 1998; Tyagi et al., 2000; Kashyap and Panda, 2001; Sepashkah and Andam, 2001).

Accurate prediction of crop water use is the key to develop efficient irrigation management practices making it imperative to develop Kc for a specific crop. Numerous studies have been conducted over the years to develop the Kc for different agricultural crops. Since most of the studies have been specific to one or two crops, Doorenbos and Pruitt (1977) prepared a comprehensive list of Kc for various crops under different climatic conditions by compiling results from different studies. Similar list of Kc was also given by Allen et al. (1998) and Doorenbos and Kassam (1979). However, Kc for a crop may vary from one place to another, depending on factors such as climate, soil, crop type, crop variety, irrigation methods (Kang et al., 2003). Thus, for an accurate estimation of the crop water use, it is imperative to use a regional Kc. Researchers have emphasized the need for regional calibration of Kc under a given climatic conditions (Doorenbos and Pruitt, 1977; and Kang et al., 2003). Therefore, the reported values of Kc should be used only in situations when regional data are not available.

- **Crop coefficient estimation**

Brouwe and Heibloem (1986) outlined the steps for development of Kc as: determination of total growing period of the crop, Kc cannot be measured directly. While ETO can be estimated using one of several available methods, ETc can be estimated by a lysimeter study (Gratten et al., 1998). A lysimeter is essentially a container that isolates soil and water hydrologically from its surroundings, but still represents the adjoining soil as closely as possible. Lysimeters can be used as a research tool to study plant-water relationships if they are designed adequately to approximate the physical system (Chow, 1964). Lysimeters provide a controlled soil-water or nutrient environment system for precise measurement of water and nutrient use and movement (Chalmers et al., 1992). Non-weighing or drainage lysimeter are used to estimate ET by computing the water balance. The water balance involves measuring all the water inputs and outputs to and from the lysimeter and the change in storage (soil moisture) over a stipulated period of time. These lysimeter provide viable estimates of ETc for longer periods such as weekly or monthly Aboukhaled et al. 1982).

2.1.1 Units of evapotranspiration

The evapotranspiration rate is normally expressed in millimeters (mm) per unit time the rate expresses the amount of water lost from a cropped surface in units of water depth. The time unit can be an hour, day, decade, month or even an entire growing period or year. As one hectare has a surface of $10,000m^2$ and 1mm is equal to 0.001m, a loss of 1mm of water corresponds to a loss of $10m^3$ of water per hectare.

2.1.2 Factors affecting evapotranspiration

i. Weather parameter.

ii. Crops factors.

iii. Management and environmental conditions.

i. **Weather parameters:** The principal weather parameters affecting evapotranspiration are radiation, air temperature, humidity and wind speed; several procedures have been developed to assess the evaporation rate from these parameters. The evaporation power of the atmosphere is expressed by the reference crop evapotranspiration (ET_o). The reference crop evapotranspiration represents the evapotranspiration from a standardized vegetated surface. The ET_o is described in detail later.

ii. **Crop factors:** The crops type, variety and development stages should be considered when assessing the evapotranspiration from crops grown in large, wet-managed fields. Differences in resistance to transpiration, crop height, crop roughness, reflection, ground cover and crop rooting characteristics results in different ET levels in different types of crops under identical environmental conditions.

iii. **Management and environmental conditions:** Factors such as soil salinity, poor land fertility, limited, application of fertilizers, the presence of hard or impenetrable soil horizons, the absence of control of diseases, pests and poor soil management may limit the crop development and reduce the evapotranspiration. Other factors to be considered when assessing ET are ground cover, plant density and the soil water content. The effect of soil water content on ET is conditional primarily by the magnitude of the water deficit and the type of soil. On the other hand too much water will result in water logging which might damage the root and limit root water uptake by inhibiting respiration.

2.2 Soil moisture content

The moisture content of a sample of soil is usually defined as the amount of water lost when dried at 105^0C, expressed either as a weight of water per unit weight of dry soil or as the volume of water per unit volume of bulk soil.

2.3 Tomato (Botanical name: *Solanum Lycopersicum esculentum*)

The tomato (Roma) is indigenous to Peru and Ecuador in South America and was probably introduced into other parts of the tropics during the 19^{th} century. It is the second most important vegetable after potato. It is grown for its edible fruits which can be eaten raw in salads, or cooked, or peeled, or made into puree, ketchup, soup or powder in canning industries. In Nigeria tomatoes are used as condiment for the stews which are a regular feature of African meals. Tomatoes are grown in all West African countries.

2.3.1 Botany

Tomatoes are dedicated plants and cannot stand by themselves (except the brush varieties), and therefore need a stake. The flowers are small and insignificant and thus do not attract insects for pollination. The corolla is yellow. Flowers arise in "trusses" (grouped of flowers on short branches), which in turn from a bunch of fruits.

2.3.2 Climate and soil requirements

Tomatoes grow well in areas with light-to–medium, evenly–distributed rainfall and with long periods of sunshine. Temperatures above 29^O C tends to inhibit fruiting. Night temperatures of $10–20^OC$ give best yields. These temperature requirements explain why a big tomato crop is produced in the northern areas of Nigeria. For best performance it is advisable to grow tomatoes during the dry season, when the sky is cloudless, but using supplemental water from irrigation. During this period, night temperatures over most of the northern parts of the countries of West Africa are between $12^{O}C$ and $18^{O}C$ because of the harmattan winds which blow from December to early February.

The soil must be deep and free – draining. It should be a fertile loam, rich in organic matter and with a pH of 5–7.5. Flowering of tomatoes is not affected by photo–period (the relative length of periods of light and dark which affect the growth and maturity of an organism). Cross pollination is effected by bumble or solitary bees but the production of parthenocarpic fruits (fruits produced without pollination) is not uncommon.

2.3.3 Varieties grown

Tomatoes are annual hairy herbs which are erect or spreading, at first green and hairy, ripen to become red or yellow, shiny, smooth or furrowed. They contain numerous, hairy, light – brown seeds. There are very many varieties. The varieties are classified according to the colour, size, shape, flavour and vitamin contents of the fruits; whether erect or sprawling; according to the earliness of yield and resistance to diseases or root – knot nematode. West African tomatoes are hardy, and produce small fruits with a sharp flavour as compared with the big fruits of temperate regions which have a mild flavour but are susceptible to leaf diseases and insect attack. This is probably why tomatoes are not normally eaten raw in West Africa.

2.3.4 Cultivation

In the large northern tomato–producing areas, land preparation starts at the beginning of the dry season in October (while planting is done in March/April in the forest region). The land is cleared of all growth and leveled with hoes, but ploughed and harrowed on big farms where 30-40 tonnes farmyard manure is applied per hectare. Tomatoes are grown from seeds which germinate in 7 to 10 days. Seeds from ripe fruit are collected, washed with diluted hydrochloric acid or washing soda and then dried. They remain viable thereafter for 3 to 4 years. Seeds are sown in nurseries or boxes at 8×8 cm or at the rate of 2 to 3 seeds per pots in soils which have been sterilized with methylbromide or formaldehyde. Those in pots are later thinned to one plant, while those from nurseries or boxes are transplanted at 4 to 6 weeks when they are 15 – 20 cm tall during the early morning or late afternoon into well – watered soil. Tomatoes are grown successfully in Nigeria using the hydroponic system. Weeding should be done regularly, using hoes. Mulching and the application of organic manure increases yield. Fertilizers (5 – 20 – 20) can be applied 7 – 10 cm from the side of each plant and about 7 cm deep at transplanting. A side dressing of sulphate of ammonia should be applied when the first fruits appear. Harvesting is done 8 – 10 weeks after planting and continues for another 6 – 8 weeks. For distance markets, fully mature, firm, green fruits are picked and are carefully packed in light wooden boxes. The fruits are cushioned with banana leaves to minimize bruising and damage during transportation. Tomatoes do not store well, hence they are sold fresh in local markets where ripe, undamaged red or yellow fruits are preferred. Canning factories in Nigeria process tomato fruits into pastes either alone or in mixtures with chillies and onion for making stew.

2.4 Lysimeter method

Lysimeter studies involve the growing of crops in small containers (lysimeter) and measuring their loss and gains. Lysimeter though provide the means of precise and direct measurements of the amount of water supplied to and lost by the crops. The soil and crops in the lysimeter should be close to the natural conditions.

Lysimeter hydrological isolated soil within them from surroundings soil and make it possible to eliminate SFL, LE, LO, while GW, RO, DP are either eliminated or measured, ET can be calculated when I, P, D, 0_1 and 0_1 have been measured. The reliability of ET data collected with lysimeter depends on how well conditions within the lysimeter (i.e soil structure and density, drainage characteristics, temperature, and density, height, e.t.c....of the crop) match conditions surrounding the lysimeter. Lysimeter must be large enough to minimize boundary effects and to a restricting root development. Mainly there are two types of lysimeters that differ in the way in which ΔS is determined. **Micro-Weighing lysimeter** and **Non Micro-weighing Lysimeters:**

- **Micro-Weighing Lysimeter:**

These are constructed so that ΔS (change in soil water storage) is determined by weighing lysimeters have a second tank that retains surrounding soil that the inside container is free weighing. They also usually have a means for removing and measuring DP and L.from irrigation point of view, weighing lysimeters are set up to enable the operation to measure the water balances water added, water retained by the soil, and the water lost through all sources-evaporation, transpiration and deep percolation. These measurements involves weighing which may be made with scale or by floating the lysimeter in water on a suitable heavy liquid, in which case the change in liquid displacement is computed against were loss from the tank. The technique yields a measurement of total water loss and is useful as an indication of field water loss, provided suitable precautions are taken. The tank must be permanently buried in the ground and surrounded by a large area of crop of the same height, if the readings made are to bear relation to losses from the crop in the field. The water table is maintained at a specific depth in the tank. Water is applied in measured amounts to the lysimeter, as irrigation is applied to the surrounding cropped area. The overflow and deep percolation, if any, are measured. This water received either from the reservoir or precipitation excluding the outflow constitutes the water used by the crop.

Weighing lysimeters differ not only in the mode of weighing but also in features of construction that affect accuracy. The most common type employs mechanical balances to measure the weight loss.

Because non-weighing lysimeter cannot provide short estimates that are needed for many studies, several types of weighing lysimeters have been developed. These are:

❖ The large Coshocton weighing lysimeters that are the earliest examples in 1958 developed by Harrold and Dreibelbis as quoted by George (2002)

❖ The Davies California lysimeter developed in 1960 by Pruitt and Angus, which is in an excellent example of a large weighing lysimeter (George, 2002). In 1961. They found that the soil in the lysimeter was unrepresentative at the wilting percentage with a perennial ryegrass (Lolium perenne) cover.

❖ The continuous weighing lysimeter such as :

▪ Csiro unit developed in 1963 by Mcllory and (Geoge,2002)

▪ The Tempe, Arizonal unit developed in 1962 by Van Bavel and Meyers.

❖ Hydraulic weighing lysimeter: they are basically of two types :

- Floating lysimeter : Two floating lysimeter have been constructed by Russian for weighing large monoliths, one by federon in 1954 and the other in 1952 by popov (George, 2002).
- A very simple hydraulic load lysimeter originated in Hawai with the separate work of Miller and Ekern in 1958 placed water filled, inflammable air mattress under soil and read the pressure with a manometer(George 2002).In 1958,Ekem constructed the first workable hydraulic load cell lysimeter by supporting a15m by 1.5m square container 0.45m deep on two auto bile inner tubes, partially inflated with water,(George2002)

❖ Monolithic lysimeter, constructed by easing a block of soil in situ, have been proposed to insure that the water distribution the lysimeter is representative. This type of lysimeter appears desirable particularly for well aggregated. Fine textured soil.

Non- weighing lysimeter

In non weighing lysimeter, there is weighing device for measuring change in soil moisture: so various techniques such as Neutron scattering, Gravimetric sampling, Electrical resistance, soil matric potential etc are used to determine ΔS.

Non-weighing lysimeter don't have the capability of having a means for removing and measuring DP and L, and second tank that retains surrounding soil so that the inside container is free for weighing in the case of weighing lysimeter.

Non-weighing lysimeter currently providing valuable data range in sizes from large area. Deep, monolith lysimeters at Coshocton, Ohio U.S.A to the small area shallow lysimeter constructed from oil drums, (George, 2002).

The Coshocton lysimeters are used for ET_o and the oil-drum type, similarly, the water table lysimeter in 1950 has been widely employed for ET_p measurement to given ET_p.

- **Lysimeter Area**:

Since the surface dimension of the lysimeter are dictated largely by the structure of the vegetation and also by the construction at the wall, lysimeter area should be large compared to the un-cropped area at the border (walls and air gap between the walls). This is necessary not only because this area contains no plants, but also because the walls and the air gap have different thermal and water properties than the soil and will affect the heat exchange. Thin wall contains made either from steel or plastic fibber glass is preferable to concrete to keep the wall gape thickness minimal.

- **Lysimeter Thermal Properties**

The lysimeter container and soil may have different thermal properties if the water distribution in lysimeter differs from that outside, the heat transfer and storage may be affected. The surface layer (25 to 40m) is of greatest importance where hourly measurement is made. Through the seasonal soil heat flux is affected by much deeper layers, if the lysimeter s shallow (even though water control suction is used). Discontinuity in thermal properties at the tank bottom can cause error in weekly or monthly measurements and temperature regulation at the bottom match the surrounds may be necessary for accuracy. Thermal mismatch error decreased when the lysimeter is covered with vegetation because the soil heat balance is decreased.

Relative error in daily measurements is less than in hourly measurement king.et.al (1958) found that with sparse alfalfa cover (following cutting), ET from a floating lysimeter given by energy balance measurement was much for daylight hours when abundant foliage was present

The thermal representative of the lysimeter also influences the thermal properties of the system; this can be determined by measuring the soil heat flux inside and outside the lysimeter and also by comparing the ratio of lysimeter ET to that given by micrometeorological methods where applicable.

Lysimeter Depth and water control

If the lysimeter is to measure ET_{a}, seve ral precaution are necessary to ensure that the root environment of the lysimeter is representative of the surrounding soil water distribution is the most important factors since it affects the water availability to the plants, soil aeration and the thermal regime (Thermal effect).

The effect of the lysimeter on the water regime as illustrated by Van Bavel's (1961) represents the initial water condition following rainfall or irrigation. At that time a zero plane is present at the bottom thereby the moisture tension as well as moisture content are different from those in the surrounding soil (a rare exception would be an impervious layer or coarse layer at the same depth as the lysimeter bottom, Tanner, 1960). These two effects, firstly, more water may be available for evapotranspiration during a prolonged dry spell. Secondly, the development of the root system of crops grown in the lysimeter may differ from that of the surrounding area.

Because the surrounding soil and that inside the lysimeter must be watered in excess of ET, lysimeter must be deep enough (or have suction control) that a good root with adequate aeration develops.

- **Lysimeter management**

The lysimeter must be sited in identical surroundings and with representative fetch. Nearby obstructions or non-evaporating surface, including balance access structure and recording instruments, paths leading to the lysimeter, roads and exposed roofs of underground shelter should be avoided. The lysimeter and the surrounds should be planted, fertilized, watered and otherwise managed in the same manner.

Water management should be planned to avoid unrepresentative salt accumulations, which can occur if the lysimeter drainage is re-circulated with the lysimeter irrigation water.

Condensation and evaporation on walls of weighing lysimeters can cause errors. In 1961, summer and Hroy found that the error due to variable condensation was intolerable when the gap between the lysimeter retaining tank and container was sealed but was acceptable when the gap was left open for vapor exchange to the atmosphere. Dehumidifying the air surrounding the tank is inconvenient but may prove necessary to eliminate condensation error.

2.5 Measurements methods of actual and reference evapotranspiration: a brief summary

Despite of the fact that evapotranspiration is the largest component of hydrologic cycle and soil water balance in most of African region, it is still difficult to accurately it determine.

Evapotranspiration determination includes various measurement techniques and modelling techniques (also direct and indirect), which simulate evapotranspiration as a biophysical process or calculate it using the empirical methods (Rana and Katerji, 2000; Katerji and Rana, 2008).

Accordingly, it is possible to distinguish between crop evapotranspiration under standard condition and crop evapotranspiration under non-standard conditions. In most cases, crop evapotranspiration in some African region refers to a non-standard condition due to agricultural water shortages. There are a great variety of methods for measuring ET; some methods are more suitable than other because of their accuracy or cost or because they are particularly suitable for given space and time scale. These methods are often expansive, demanding in terms of accuracy of measurement and equipment management. Although the methods are inappropriate for routine measurement, they remain important for the evaluation of ET estimates obtained by indirect methods.

The methods of measuring ET should be divided into different categories, since they have been developed to fulfil very different objectives. One set of methods is primarily intended to quantify ET over a long period of time, from weeks to months and to growth season. Another set of methods has been developed to understand the process governing the transfer of energy and matter between the surface and atmosphere. The last set of methods is used to study the water relations of individual plants or parts of plants.

- **Direct measurement at the plot scale: the weighing lysimeter**

Weighing lysimeter (called also "evapotranspirometer") was developed to provide a direct measurement of ET. A lysimeter is a device, a tank or container, used to define the water movement across a boundary. Actually, only a "weighing lysimeter", can determine ET directly from the mass balance of the water, as contrasted to a non-weighing lysimeter which indirectly determines ET from the volume balance (Howell et al., 1991).Thus, weighing lysimeter are usually containers placed in the field with soil cultivated in the same way as the surrounding field. The lysimeter leans on sensor (a balance) capable of measuring the weight variation due to loss of water by the system soil-canopy atmosphere. However, the weighing lysimeter data are not always representative of the conditions of the whole field but, often, they only represent the ET of one point in the field (Grebet and Cuenca, 1991). If the lysimeter surface and area immediately around it are surrounded by drier vegetation or bare soil an oasis effect can occur. Net radiation in excess of latent heat is converted to sensible heat which is transported toward the lysimeter, resulting in a net supply of energy to the lysimeter vegetation. All these defaults cause an increase of ET as compared to the surrounding crop. This overestimation of ET can be particularly important in a high radiation climate such as in the Mediterranean region (Howell et al., 1991; 1995). The weighing lysimeter, spite of the problems and inconveniences that limited its use, is often considered to be the reference method, and is used in particular for well-watered crops to test the other ET measurement methods.

- **Indirect measurement at the plot scale: micrometeorological approach**

From the energetic point of view, evapotranspiration can be considered as equivalent to the energy employed for transporting water from the inner cells of leaves and plant organs and from the soil to the atmosphere. In this case, it is called "latent heat" and is expressed as energy flux density (Wm^{-2}). Under this form, ET can be measured with the so-called "micrometeorological" methods. These techniques are physically-based and carried out by applying the laws of thermodynamics and of transport of scalars into the atmosphere above the canopy. To apply the micrometeorological methods, it is usually necessary to measure meteorological variables with sensor and suitable equipment placed above canopy. Micrometeorological methods measure the actual ET with error on the final value of ET around a fraction of mm of water. Thus, they remain very suitable methods for measuring ET in semi-arid and arid environments, where the values of ET are often very low during drought periods (from spring to summer). The only exception is the aerodynamic method, which can be used only below a crop height of 1.5 m. Another advantage of the micrometeorological technique lies in the fact that they give accurate ET values on different time scales: the hour, the day and, consequently, also the week and the whole season. Therefore, they can be adopted for studying the theoretical aspects of water consumption and the response of the crop to the water supply. The micrometeorological methods cause small disruptions in the soil-canopy-atmosphere environment, since they require small sensors easy to install, even though good knowledge of electronics and informatics is needed. The micrometeorological methods include the Bowen ratio, the eddy covariance and the aerodynamic one.

- **Measurement on the plant scale**

These methods measure water loss either from a whole single plant or from a small group of plants. They cannot directly supply the ET on the plot scale. To achieve this purpose, it is necessary to adopt a specific methodology for each situation, in order to achieve the up scaling from the measurement at the plant level to the ET on the plot scale. These methods include the tracer method, porometry, the sap flow and the chamber system.

The direct estimation of evapotranspiration

Direct crop evapotranspiration measurement methods are expensive and hard work demanding, and the results only apply to the exact conditions in which they were measured. Because direct methods are impractical for permanent use on a large scale, ET is often and commonly estimated, both for practical and research purposes. The most models diffuse are: Penman equations (1948, 1956), Monteith equations (1963, 1965) and Penman-Monteith (P-M) model (1965). The Penman equation is not relative to the crop. It concerns the evaporation from a given surface when all surface-atmosphere interfaces are wet (saturated). In this model evaporation can be calculated from the available energy and from the convective fluxes. The model has been extended by Penman (1956) to the particular case of a leaf, thanks to the introduction of the concept of "resistance" analogous to Ohm's law. According to this approach, an energy flux density can be considered as directly proportional to the difference of potential and inversely proportional to the resistance encountered. The scaling-up of the Penman model (1956) was carried out by Monteith (1965), thanks to the "big leaf surface" concept. According to this hypothesis, the canopy can be thought as a single large leaf, by supposing that the sinks and the source of heat and vapour fluxes can be found at the same layer of the momentum flux sink. Finally, the combination of the three previous equations leads to the general model for estimating the actual crop evapotranspiration, generally known as the "Penman- monteith model". This it is largely accepted by scientific community thanks to its effectiveness. It is an interesting tool for analysis the relationship between ET and environmental factors but it suffers of the huge difficulty to have correct values of canopy resistance (Katerji and Rana, 2006; Todorovic, 1999; Lecina et al., 2003; among many others). Thus, the best way to calculate

ETc is using a direct mode, without an intermediate calculation for a reference surface. To achieve this aim, the ensemble of biological and physical characteristics of each vegetal surface, involved in the ETc, must be taken into account: i.e.

i. The albedo, taking into account the reflection of the solar radiation and the architecture of the leaves in the determination of the available energy A,

ii. The height and roughness of the crop which take part of the calculation of the convective exchanges,

iii. The leaf surface and the stomatal conductance which take part of the calculation of the canopy resistance to the transfer of the water between the surface and the atmosphere. It similarly applies a Penman-Monteith type formula. However, in this method the canopy resistance, is specific for each species, it is not constant but variable in function of climatic characteristics of the atmosphere below the top of the boundary layer above the crop. Its determination is based on modelling works proposed in the scientific literature (see for example Jarvis, 1976; Katerji and Perrier, 1983; Orgaz et al., 2005). These models need also that the determination of the weather variables should be made above the considered crop. For this reason the direct method is considered as not operational. A largely spread direct model to estimate ETc is well described in detail in Katerji and Rana (2008).

2.6 FAO-Penman-Monteith method

The FAO-PM (Allen et al., 1998) is the standard method of ETo estimation. Allen et al. (1998) described the methodology of estimating ETo using FAO-PM.

$$ET_o = \frac{0.408\Delta\,(Rn-G)+\gamma\frac{900}{(1+273)}U2(es-ea)}{\Delta+\gamma(1+0.34U2)} \qquad (2.1)$$

Where R_n is the net radiation at the crop surface [MJ m-2 day-1],

G is the soil heat flux density [MJ m-2 day-1],

T is the mean daily air temperature at 2 m height [°C],

u_2 is the wind speed at 2 m height [m s-1],

e_s is the saturation vapor pressure [kPa],

e_a is the actual vapor pressure [kPa],

e_s-e_a is the saturation vapor pressure deficit [kPa],

Δ is the slope vapor pressure curve [kPa °C-1],

γ is the psychometric constant [kPa °C-1].

CHAPTER THREE

3.0 MATERALS AND METHODOLOGY

3.1 Study Location

The case study of this project is Federal University of Technology, Minna permanent site. The area has a total land mass of eighteen thousand nine hundred hectares (18,900 ha) which is located along kilometer 10 Minna–Bida Road, South–East of Minna under the Bosso Local Government Area of Niger State. It has a horse–shoe shaped stretch of land, lying approximately on longitude of 11.30^0 N and latitude of 3.20^0 E with an elevation of 848m. It is one of the states in Nigeria that lies in the semi-arid zone. (Desk diary, Niger State, Ministry of Information and Communication Minna, 2011).

3.1.1 Vegetation and Land Use

Minna falls within the semi-wood land or tree forest vegetation belt with derived dry grass or shrub land known as the southern guinea savannah. This is also known as the transition belt, which lies between the savannah grass/shrub land of the north and the rain forest of the south. Due to intensive fallow type of agricultural practice and grazing of the land, the area is dominated by stunted shrubs; interspersed with moderate height tree and perennial foliage. .

3.1.2 Climate

Niger state experiences distinct dry and wet-seasons with annual rainfall varying from 1,100mm in the northern part to 1,600mm in the southern part. The maximum temperature (usually not more than 35 ^{0}C) is recorded between March and June, while the minimum is usually between December and January. The rainy seasons last for about 150days in the northern parts to about 120days in the southern parts of the state. Generally the fertile soil and hydrology of the state permit the cultivation of most of Nigeria's staple crops and still allows sufficient opportunities for grazing, fresh crops. (Desk diary, Niger State, Ministry of Information and Communication Minna, 2011).

3.1.3 Rainfall

Minna generally is known to experience rainfall from the month of May to the month of October and on rear occasions, to November. It is known to reach its peak between the months of July and August.

2.1.4 Temperature

The maximum temperature period in this area is usually between the months of February, March and April which gives an average minimum temperature record of 33^0C and maximum temperature of 35^0C (Minna Airport Metrological Centre, 2000). During the rainfall periods, the temperature within the area drops to about 29^0C.

2.1.5 Soils of the Area

The soil types in Niger state are two; Ku-soil and Ya-soil; The Ku-soil has little erosion hazards, while the Ya-soil has better water holding capacity. This has so far encouraged the residents of Minna metropolis and neighboring villagers to use the land for agricultural activities (Desk diary, Niger State, Ministry of Information and Communication Minna, 2011).The figure below show the project location (Federal University of Technology Minna)

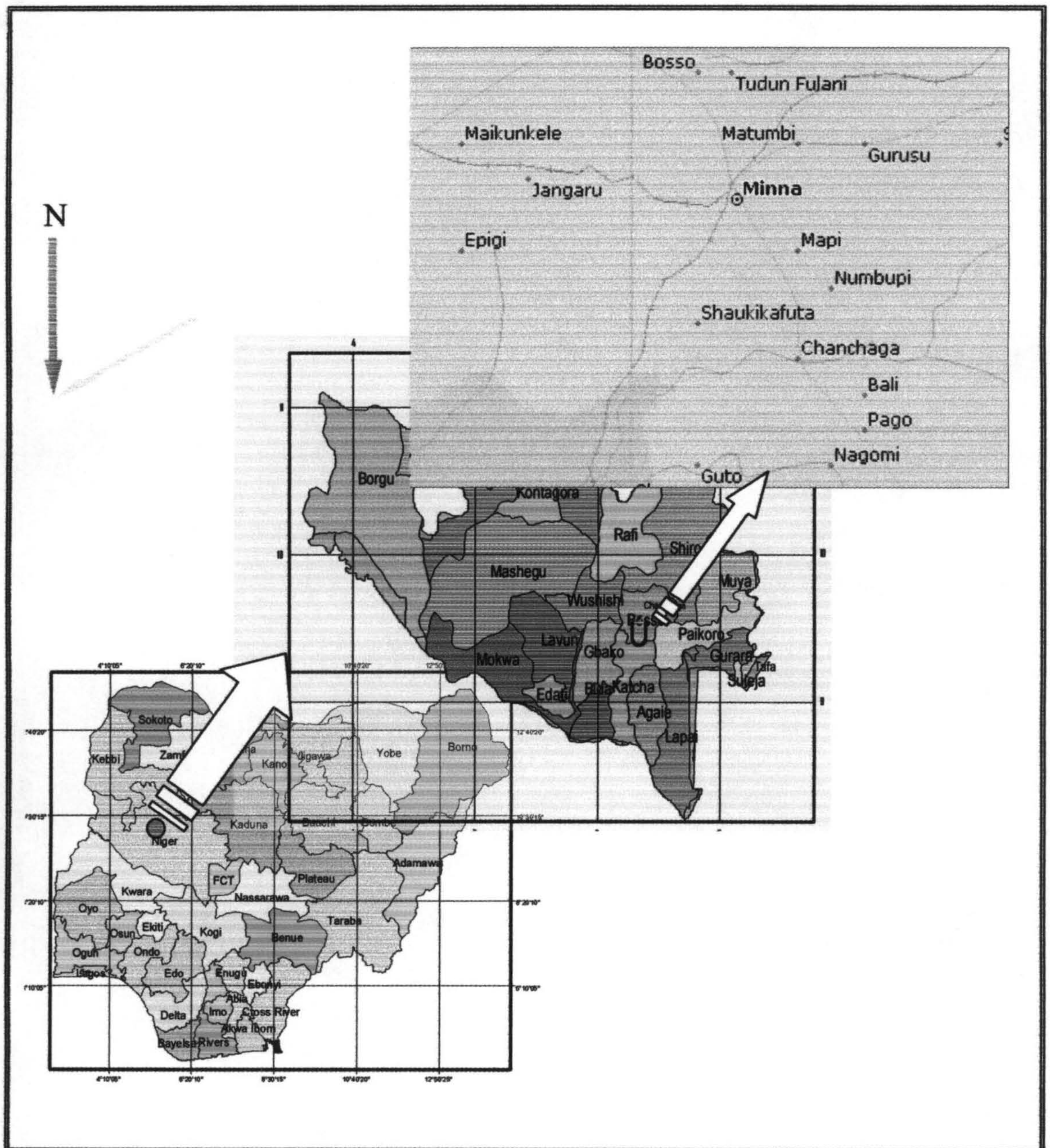

Fig. 3.0: Study Location at Bosso Local Government Area, Niger State

3.2 Materials:

The materials used to obtain the required data include; Micro-weighing Lysimeter, Knapsack Sprayer, Soil sample, Rain Gauge.

3.2.1 Micro-Weighing Lysimeter

This has the following dimensions: height of 1500mm, width of 500mm, and depth of 200mm.

3.2.2 Knapsack Sprayer:

This is a pressurized device that was used to apply water into the Vespa motorcycle tube through the flexible-tube.

3.2.3 Soil Sample:

The soil used for this experiment was a sandy loamy soil (fine particle) it has a pH of 6.0, organic matter percent of 1.06%, and moisture content of 18.5%.

A Sieve Shaker was used to sieve the soil.

3.2.4 Rain Gauge

A Non-recording rain gauge was setup for normal collection of rainfall, measured by a network of rain gauge. The non-recording rain gauge consists of a copper vessel, funnel with a curtailer rim and a glass bottle as receiver. The cylindrical metal casing is fixed vertically to the masonry foundation with the level rim above the groom surface. The rain falling into the funnel is collected in the receiver, which is measured in a special measuring glass graduated in mm. Plate 3.1 show the rain gauge set-out bellow.

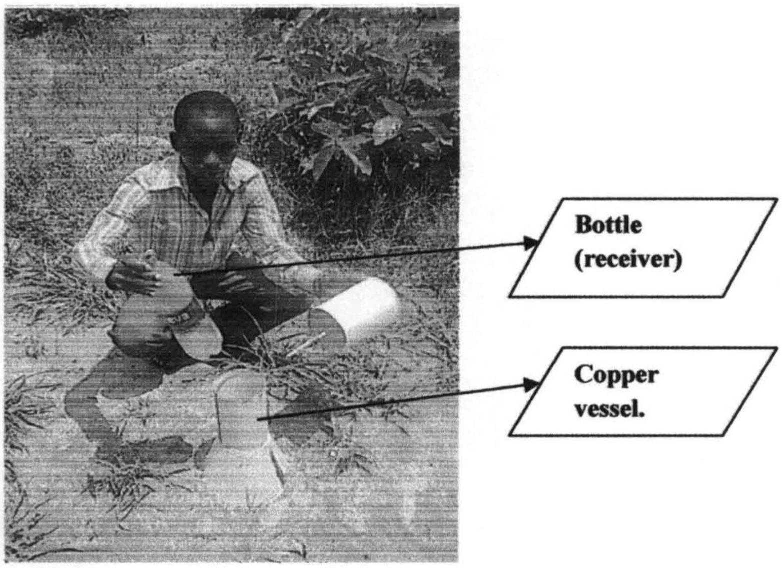

Plate 3.1 Rain Gauge Set-out in the site.

3.3 Site Location and Installation

The field trial was carried out during the 2011 rainy season at the experimental field of the Department of Agricultural and Bio-resources Engineering at Federal University of Technology, Minna, Gidan kwano campus. Before the installation of micro-weighing lysimeter on the site a foundation of depth 500mm, width of 800mm and length of 2800mm was dug in order for the lysimeter to be installed inside. Plate 3.2, 3.3 and 3.4 shows the installation, dug of pit at the site and sloped-shape of the lysimeter, illustrated bellow.

Plate 3.2 Dug of Pit at the Installation site. Plate 3.3 Installation of the Lysimeter setup.

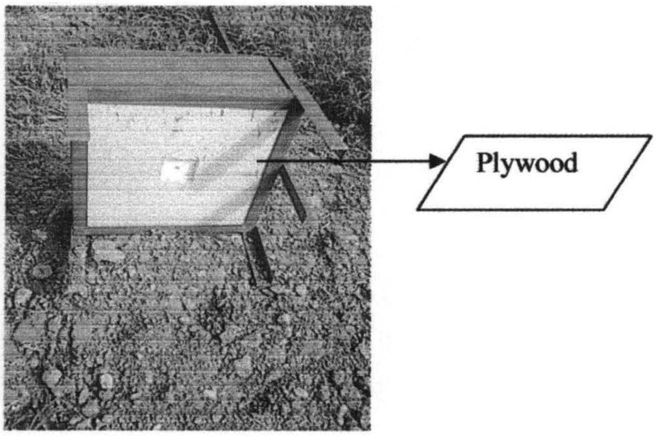

Plate 3.4 Sloped shape of lysimeter.

3.4 Lysimeter Construction

A total of three Micro-weighing lysimeter were constructed. Each Lysimeter was constructed from metal steel-sheets, the sheet were welded together using metal arc welding techniques. The steel angle iron was welded to the sheets at the joints and corners. It is to purify the ETi and ETo for tomato crop. Metal steel-sheet of 16gauge was cut into 500mm by 500mm and 200mm in height. This was used to construct the four corner of the lysimeter and a angle iron of 200mm was used to brace each side of the metal sheet with 200mm by 200mm used for the four stands, beneath the four corners of the metal steel-sheet, each was an angle iron of 500mm by 500mm welded on to it to support the piece from the ground. Horizontally, plywood of 490mm by 480mm with an opening of 12mm by 12mm was seated on the angle iron. Plate 3.5 Show the Lysimeter layout for the tomato crop. The hole so created is to allow the passage of the flexible tube from the bottom of the bucket reach the plastic container below, to drain the percolation of water from bottom of the bucket. A Vespa motorcycle tube filled with water was placed on the plywood. Plywood of the same construction was placed on top of the tube. While the tube-valve was fitted to a flexible tube, at the other end of the flexible tube was fixed a meter rule to denote the change in the level of water inside the tube. Plates 3.6 show the set-up of the flexible tube and vesper tube, as illustrated bellow. This in turn displayed increase and decrease in weight of the lysimeter tank (described below), standing on the plywood. Seated below the whole arrangement was a graduated empty table water plastic container to collect drained percolating water from the lysimeter tank.

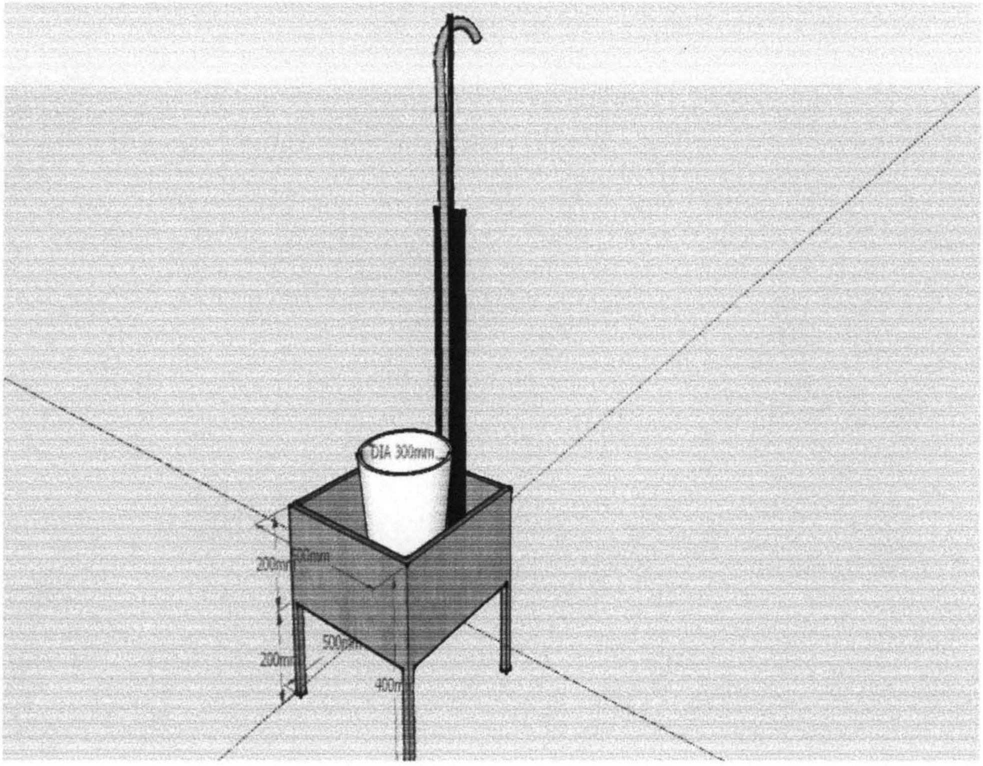

Plate 3.5 Lysimeter layout for the tomato crop

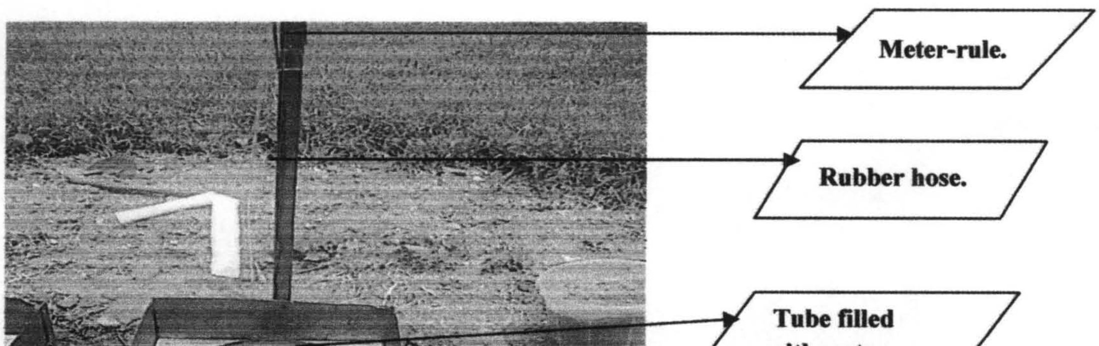

Plate 3.6 Placement of Vesper-tube in the Lysimeter.

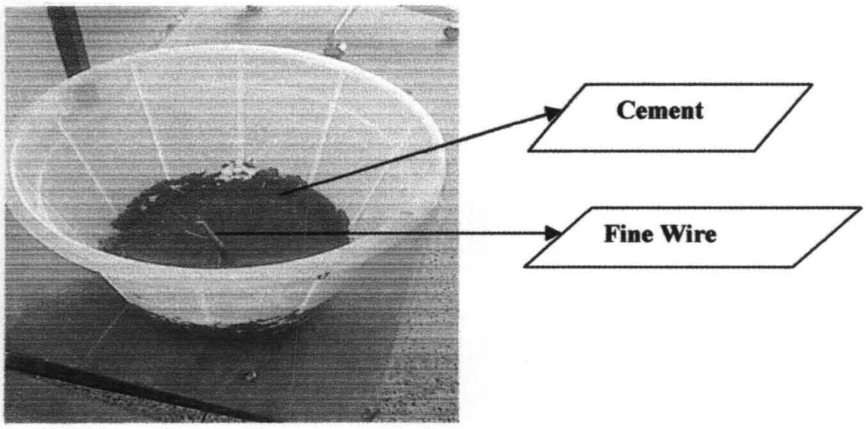

Plate 3.7 Casted bucket.

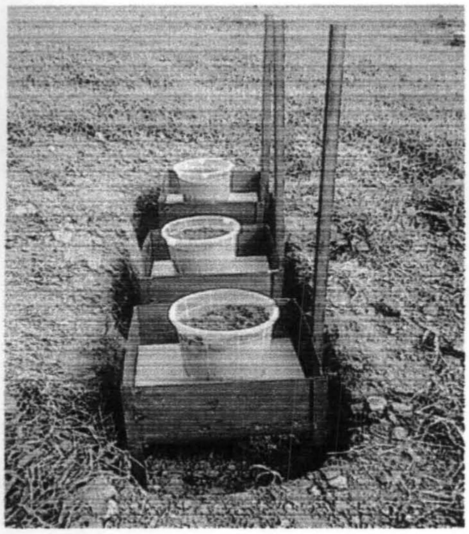

Plate 3.8 Lysimeter Placement in pit.

Plate 3.9 Day of Transplanting in the site.

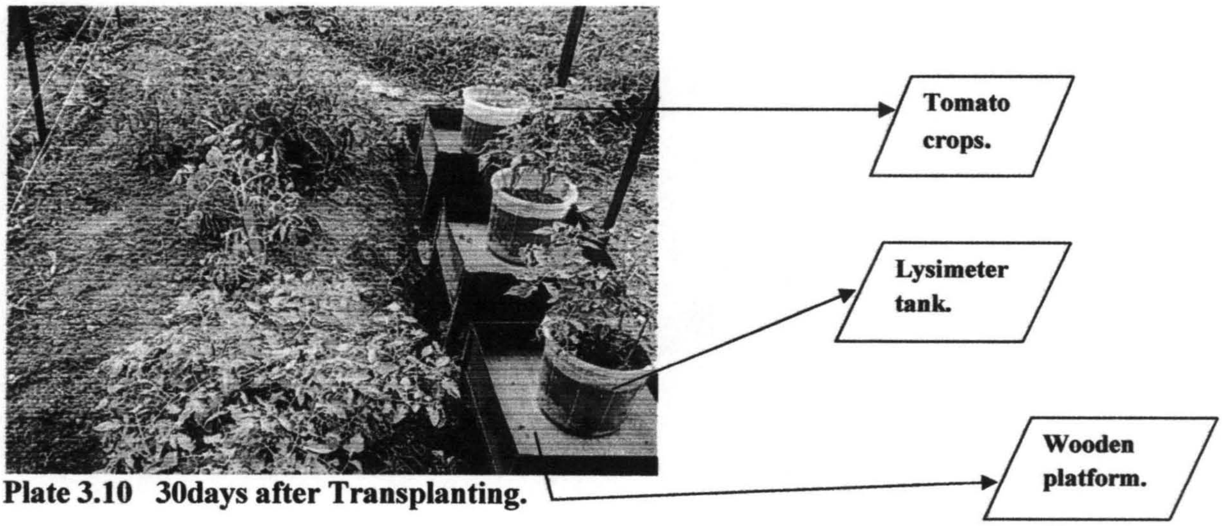

Plate 3.10 30days after Transplanting.

The inside of the bucket was casted. Then allowed to drain for a days, a wire net was placed on it, in plate 3.7. On the net was a small quantity of a sandy soil placed to allow easy infiltration and on it was a desired bulk density of loamy sandy soil say 20kg filled into the bucket. The bucket was then saturated and allowed to drain for two days to achieve field capacity. The drainage bottle was emptied and initial meter rule reading was recorded and noted before every rainfall. The rainfall depth (mm), the change in soil moisture and drainage were recorded.

3.5 Calibration and testing

The Micro-weighing lysimeter was setup for calibration and testing. The weight of an empty bucket was recorded using an Electronic weighing balance. A stone was added unto the bucket, re-weighed and new-weight recorded. This process was repeated ten times, adding one stone each time-till we had ten stones in the bucket.

The height of an empty bucket was also recorded using Micro-weighing Lysimeter. A stone was added unto the bucket and new height was determined. This process was repeated ten times, adding one stone each time, till we had ten stones in the bucket. As illustrated in the plate 3.11 and a graph in figure 3.1

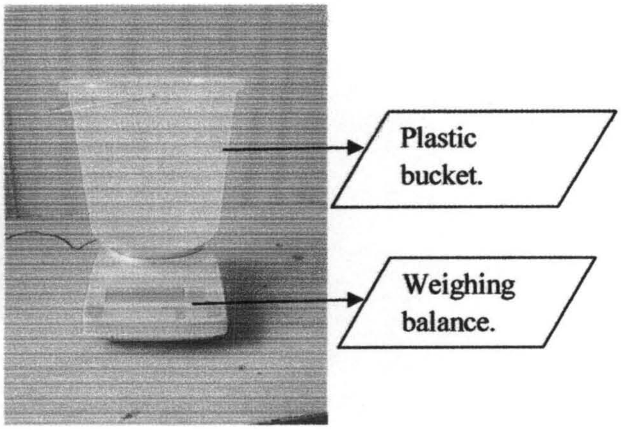

Plate 3.11 Determining the weight and height.

3.6 Estimation of crop water use from the lysimeters

Each rainfall added water to the lysimeter tank. As a result, the pressure exerted on the tubes due to increase in weight of the lysimeter tank caused a rise in the water level in the flexible tube. Excess water beyond what the soil could hold drained by gravity through the bottom of the lysimeter tank into the drainage collector. As evaporation took place and the crop used water for its metabolic activity on daily basis, the weight of the lysimeter tank and consequently the level of water in the flexible tube decreased. The levels of water in the flexible tubes were monitored every morning throughout the crop growing season. The drainage collector was also inspected three days interval, and the depths of water found in them were also noted. The difference in weight of the lysimeter tank consecutive measurements indicated the difference in the level of water in the flexible tube was as a result of the water added from rainfall, crop water use (evapotranspiration). When there is no rainfall, the difference in weight would be due to crop water use. The weight of the lysimeter tank on any given day was determined from the level of water in the flexible tube using a relationship early developed in the between height of water in the flexible tube and known weight packed into the lysimeter tank. The relationship was obtained as:

$$W = 0.006 \times H - 12.81 \qquad (r^2 = 0.989)$$

Where, W is weight of lysimeter in kg and H is height of water in the flexible tube in cm. figure 3.2 illustrated bellow.

The differences in weight of the lysimeter tank thus obtained on daily basis were translated to depth of water in mm/day using a factor of 14.1.

This factor was based on the surface area of the lysimeter tank and the density of water. When rainfall, drainage events occurred and the readings where take-in for three days interval, the depth was first subtracted from the change in weight of the lysimeter tank, and the reminder was the crop water use. The expression used for the computation of daily crop water use is given as:

$$ET_i = P_i - R_{fi} - D_i - [(W_{i+1} - W_i) * cf] \qquad (3.1)$$

Where, P_i = Rainfall amount (mm) of day *i* collected in the rain gauge

R_{fi} = Runoff (mm) of day *I*, i.e (R_{fi}=0).

D_i = Drainage (mm) of day *i*.

W_i = Weight of the lysimeter soil on day *i*.

W_{i+1} = Weight of the lysimeter soil the next day at an interval of 24 hours.

ET_i = Crop water use of day i

cf = A factor converting weight to equivalent depth of water (cf =14.1)

Therefore: cf = a factor converting weight to an equivalent depth of water.

Where, Density (kg/m^3) = $\frac{mass\,(kg)}{Volume\,(m3)}$

$D = 30cm = 0.3m$

$$A = \frac{\pi}{4}(0.3)^2$$

$A = 0.071\ m^2$

$$depth = \frac{1000}{0.071} = 1408. = \frac{1408}{100} = 14.1$$

3.7 Experimental Crop

Tomato (Lycopersion esculentum L. cv.Tristar): Tomato seeds were sown in the nursery-bed on 04 July 2011. The land is well tilled to the required depth and neatly prepared with rich organic matter. The nursery-bed was watered, broadcast the seedling. A thin layer of soil was spread on the bed to cover the seed lightly. Shade was provide to protect the seedling from hot-sun and heavy rainfall. Kept in a growth chamber until 03rd August, 2011, and then transplanted to lysimeter tanks, D_1, D_2, and D_3. A total of sixteen seedlings were planted within and outside the lysimeter, keeping plant to plant and row to row distances of 0.50m.Weeding was done as need arises after transplanting. No-fertilizer was applied during the growing season. Manure was applied at recommended rates 4-6 weeks after transplanting. Fruit were picked twice (14Spet and 20Spet, 2011) during the growing season, and the total yield was determined.

Table 3.0 Costs for Micro-weighing Lysimeter Construction.

S/No	Items	Cost(₦)
1	Angle-iron	1,600
2	Plywood	4,500
3	Flat sheet	4,500
4	Steel-ruler	1,500
5	Vesper-tube	1,050
6	Flexible tube	250
7	Work manshipe	7,000
8	Lead	200
9	Rubber bucket	900
10	Local transportation and travels	2,000
11	T-square	1,500
	Total	₦25,000

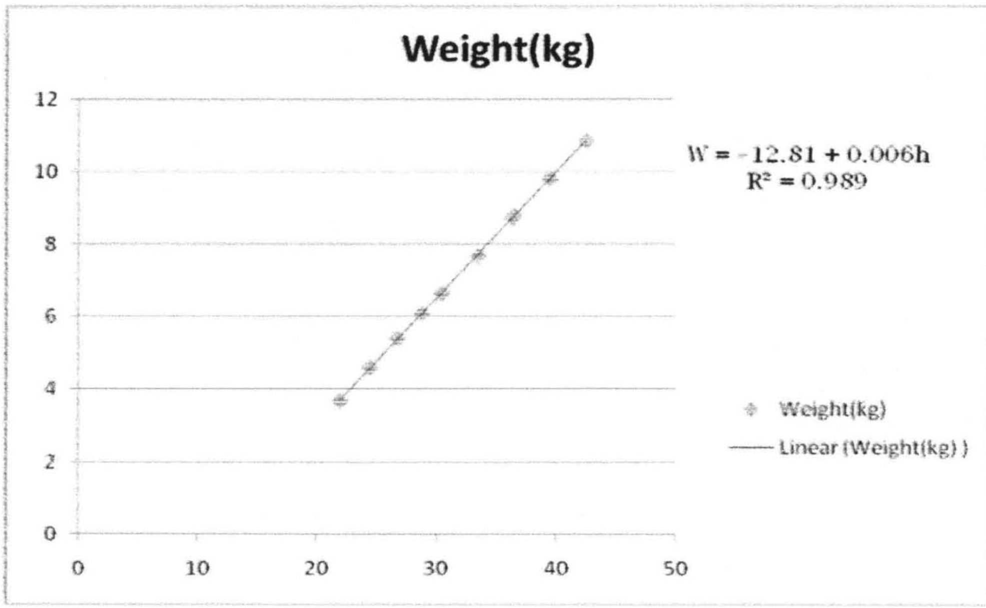

Figure 3.1 Lysimeter calibration and testing.

CHAPTER FOUR

4.0 Results and discussion

4.1 Results

4.1.1 Results from Lysimeter

The general water balance equation was used to obtain the crop water use from tomato (*Lycopersion esculentum*) in mm/day as measured with lysimeter D_1, D_2 and D_3, presented in Table 4.1. The expression used for the computation of daily crop water use is given as:

Hence at the first reading, date 03-Aug-11. ET_i was obtained to be:

$$ET_i = P_i - D_i - (w_{i+1} - w_i) \times cf$$

$$= 8 - 5 - (17.19 - 19.23) \times 14.1$$

$$= 31.76 \text{mm/day}$$

Based on above calculation, Table 4.1 was generated.

From Table 4.1, the ET_i of tomato is 23.84mm/day, obtained during the flowering stage i.e, 18 days after transplanting on 20-Aug-2011.

4.1.2 Results from Hargreaves FAO-56 Method.

Computation of ETo, using Hargreaves FAO-56 Method, is based on climatic parameters; solar radiation, temperature (max, min and mean) and wind is presented in appendices.

$$ETo = 0.0023Ra\,(T_{max} - T_{min})^{0.5} \times (T_{mean} \times 17.8) \qquad (4.1)$$

Where, Ra= Extraterrestrial radiation

T_{max} = maximum air temperature

T_{min} = minimum air temperature

T_{mean} = mean daily air temperature

Computing ETo during the initial stage 1: (Vegetative stage) 08-Aug-2011.

$$ETo = 0.0023 \times 0.0575 \times (28-21)^{0.5} \times (28+21/2)$$

$$= 1.3 \times 10^{-04} \times 2.65 \times 24.5$$

$$= 0.015\text{mm/day}.$$

For stage 2: (Flowering) 20-Aug-2011.

$$ETo = 1.3 \times 10^{-04} \times 2 \times 43.8$$

$$= 0.012\text{mm/day}.$$

For stage 3: (Fruiting to maturity) 16-Sep-2011.

$$ETo = 0.013\text{mm/day}.$$

Based on the above calculation Table 4.1 was generated.

Table 4.1: Record of Rainfall, Drainage ET_i and ETo of the tomato crop growing season.

State: Niger.

Crop Type: Tomato (*Lycopersion esculentum*)

Season: 04-July-2011 to 01-Oct-2011.

Place: Minna

Development of complete Vegetative, Flowering and fruiting stage.

Date	Height(cm)	Weight(cm)	Rainfall(mm)	Drainage(mm)	ET_i(mm/day)	ETo(mm/day)
3-Aug-11	637	25.41				
4-Aug-11	610	23.79				
5-Aug-11	606	23.55	8			
6-Aug-11	534	19.23				
7-Aug-11	520	18.39				
8-Aug-11	500	17.19		5	31.76	0.015
9-Aug-11	512	17.91	27			
10-Aug-11	519	18.33				
11-Aug-11	512	17.91		12	20.92	0.013
12-Aug-11	521	18.45				
13-Aug-11	540	19.59	19			
14-Aug-11	514	18.03		15	26.00	0.011
15-Aug-11	421	12.45				
16-Aug-11	413	11.97				
17-Aug-11	499	17.13	23	10	21.69	0.011
18-Aug-11	428	12.87				
19-Aug-11	413	11.97				
20-Aug-11	414	12.03		11	23.84	0.012
21-Aug-11	409	11.73	28			
22-Aug-11	415	12.09				
23-Aug-11	402	11.31		18	21.00	0.009

24-Aug-11	404	11.43				
25-Aug-11	415	12.09	11			
26-Aug-11	400	11.19		0	23.69	0.009
27-Aug-11	408	11.67				
28-Aug-11	403	11.37				
29-Aug-11	380	9.99		14	13.92	0.014
30-Aug-11	396	10.95				
31-Aug-11	392	10.71	34			
1-Sep-11	370	9.39		29	23.61	0.015
2-Sep-11	376	9.75				
3-Sep-11	350	8.19				
4-Sep-11	378	9.87	9	8	19.23	0.014
5-Sep-11	359	8.73				
6-Sep-11	340	7.59	16			
7-Sep-11	340	7.59		8	33.07	0.006
8-Sep-11	329	6.93				
9-Sep-11	312	5.91				
10-Sep-11	310	5.79		10	31.38	0.012
11-Sep-11	300	5.19	4			
12-Sep-11	310	5.79				
13-Sep-11	270	3.39		3	34.84	0.013
14-Sep-11	271	3.45				
15-Sep-11	265	3.09	41			
16-Sep-11	267	3.21		18	21.31	0.006
17-Sep-11	295	4.89				
18-Sep-11	269	3.33				
19-Sep-11	279	3.93		5	25.85	0.016
20-Sep-11	272	3.51				
21-Sep-11	260	2.79	32			

22-Sep-11	270	3.39		18	5.54	0.016
23-Sep-11	250	2.19				
24-Sep-11	235	1.29				
25-Sep-11	237	1.41		15	44.92	0.016
26-Sep-11	217	0.21				
27-Sep-11	218	0.27	18			
28-Sep-11	216	0.15		10	9.69	0.015
29-Sep-11	215	0.09	29			
30-Sep-11	220	0.39				
1-Oct-11	212	-0.09		15	20.76	

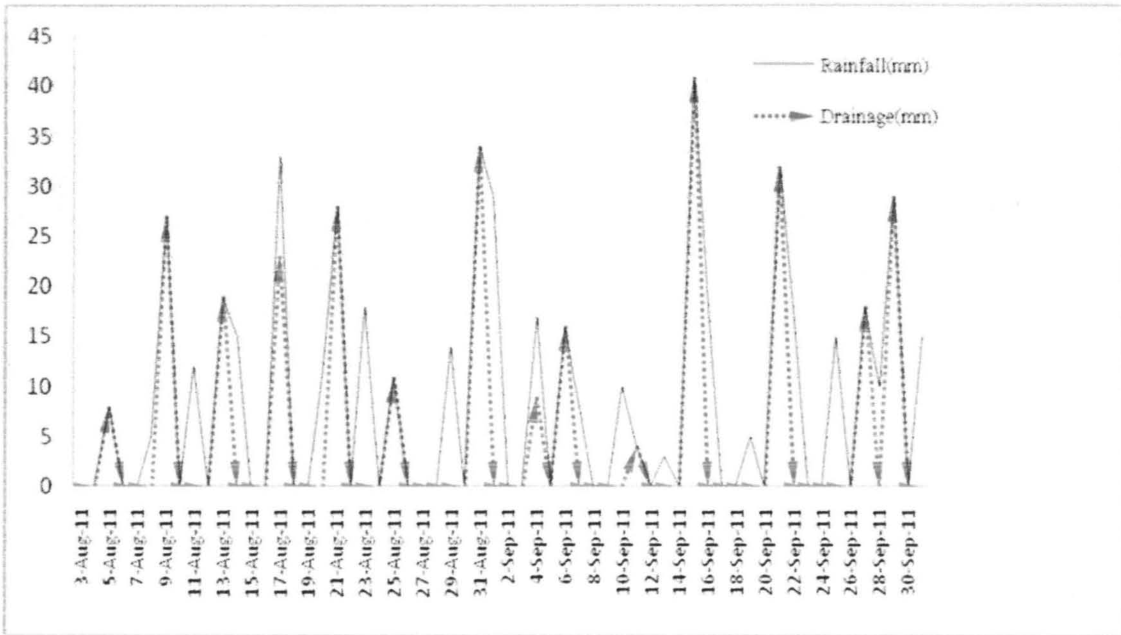

Fig.4.0: Graph of Rainfall depth and drainage from the tomato lysimeter

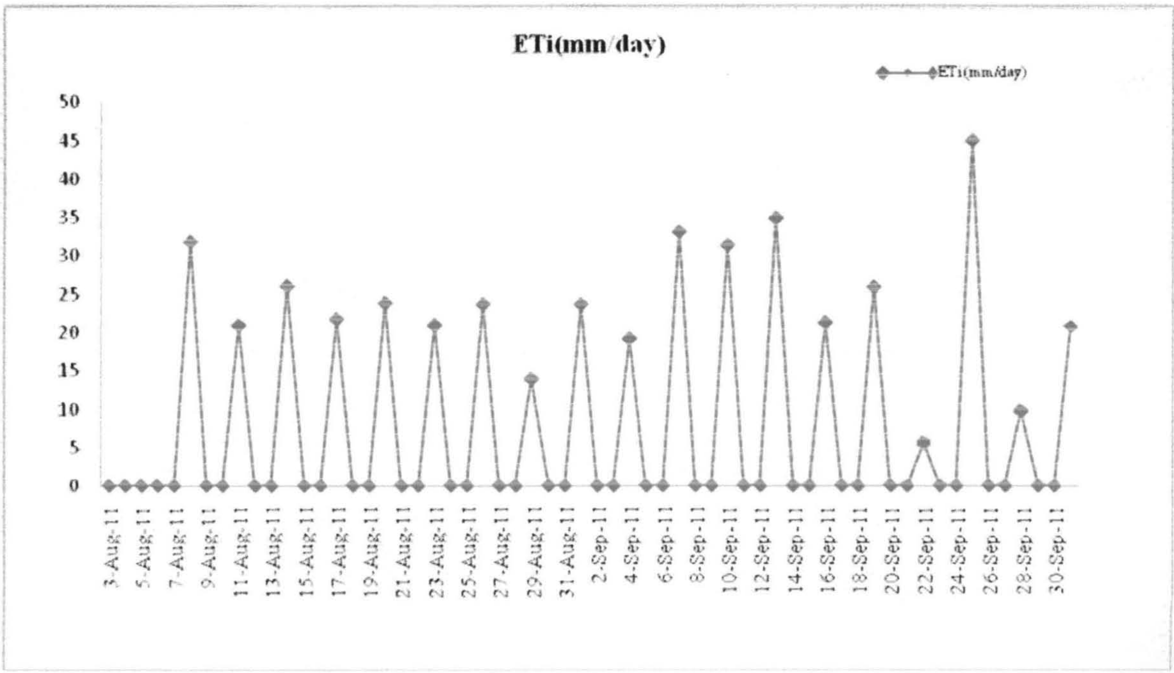

Fig.4.1: Graph of Daily crop water use of the tomato crop

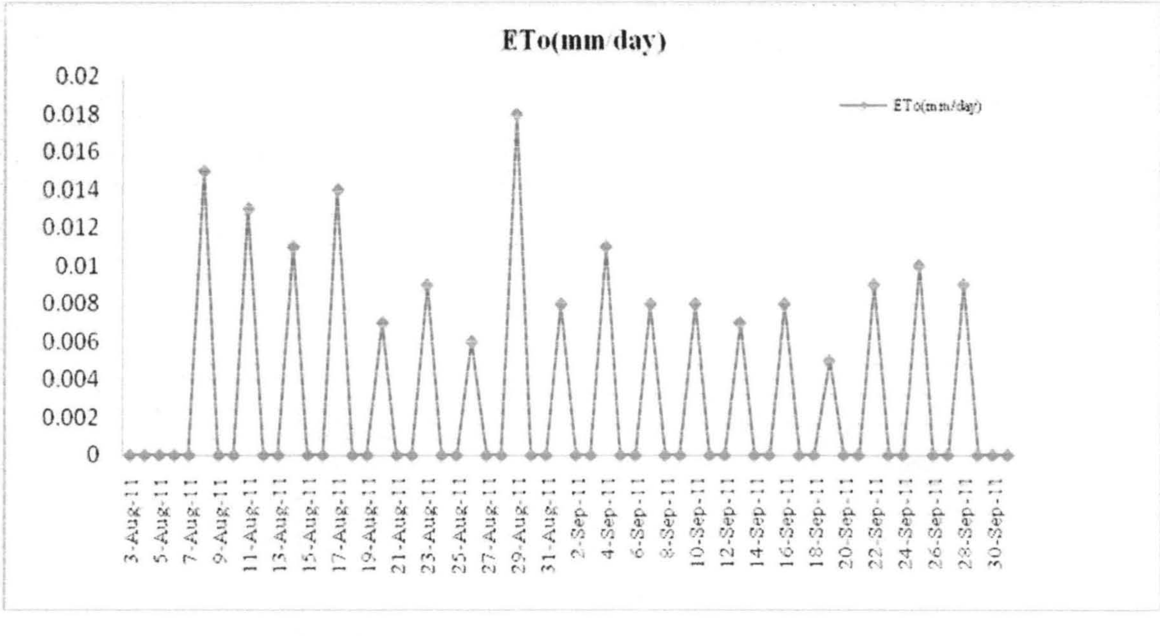

Fig.4.2: Graph of Daily reference evapotranspiration of tomato crop

4.1.3 Yield results

The surface are of the lysimeter tank is:

$$A = \frac{\pi}{4}d^2 \tag{4.1}$$

Where, d is diameter of the bucket = 0.3m

$$A = \frac{\pi}{4}(0.3)^2$$

$$A = 0.071\ m^2$$

The yielding during the first harvest is:

$$Z_1 = \frac{12.4}{0.071} = 174.6 g/m^2$$

At second harvest:

$$Z_2 = 690.1 g/m^2$$

4.2 Discussion of results

4.2.1 Rainfall and drainage depths

Figure 4.0 Show the graph of depths of rainfall and drainage from the tomato lysimeters D_1, D_2 and D_3, respectively. A total of 14 rainfall events were recorded in the tomato fields, respectively. The rainfall depths varied from 4 to 41 mm (Table 4.1). The peak rainfall amount was experienced in August and September as it is the characteristics of rainfall in the study location. The seasonal rainfall depth in the tomato fields was 299, respectively. This was simply due to planting dates and dates of start and end of data collection for the crops. The drainage depths varied from 0 to 29 mm, respectively. However, the seasonal drainage of three days interval from the tomato lysimeters was 224 mm, respectively. The seasonal drainage from the tomato lysimeters was about 27%, respectively of the total rainfall recorded.

4.2.2 Daily crop water use

Figure 4.1 Show the trend of the daily crop water use of the tomato crops during the growing season. The daily crop water use of the tomato crop varied from 5.54 to 44.92 mm/day. There was no definite pattern for the daily crop water use with respect to crop age as the values kept rising and falling throughout the crop growing season. This is typical of daily evaporation during the rainy season as higher evaporation does happen on very sunny and cloudless days and lower evaporation on cloudy and rainy days.

4.2.3 Comparisons of estimated reference evapotranspiration (ETo)

Figure 4.2 Show the potential crop water use (ET_c) and the crop water use estimated using the Micro-weighing micro-lysimeters (ETo) for the tomato crop, respectively. The ETo compared closely with ETc for the tomato crops, respectively, which implies that the weighing micro-lysimetry effectively estimated the crop water use of the crops.

4.2.4 Graph Interpretation

The rate of ETi during the early stage of tomato (Vegetate stage) increases. After this stage the rate of the ETo becomes very high and when the crop attained its peak ETi decreases at the flowering stage which extended to the fruiting stage and during the maturity stage the rate of ETo decreases.

From the Hargreaves FAO-56 method it appears that the rate of ETo during the early stage (0.015mm/day) is higher than those computed during the flowering and fruiting stages.

Therefore, it should be noted that the rate of the ETo is highly influenced by temperature, wind, relative humidity and solar radiation. The Micro-weighing lysimeter method gives more accurate results than the Hargreaves FAO-56 method at this was generated based on the meteorological parameters only.

4.3 Crop

Tomato crop has three growth stages namely:

i. Vegetative stages: sowing to complete vegetative cover.

ii. Flowing stage: flowering to fruiting.

iii. Fruiting stage: fruit to maturate. Plate 3.9 and 3.10.

CHAPTER FIVE

5.0 Conclusion and Recommendations

5.1 Conclusion

A three months lysimetric study was conducted between the month of August to October, 2011 at, the experimental field of Department of Agricultural and Bio-resource engineering, Federal University of Technology, Minna. To assess water use of tomato using lysimeter and an empirical formula to determine (ETo). Compare the water use with that of weather based data. Three micro-weighing lysimeters were designed, constructed, calibrated, tested and installed for this purpose. Instrumented to monitor drainage, change in weight, with standard rain gauge to record precipitation. The data obtained were translated to crop water use and (ETo) was determined.

The values obtained were found compared closely with that of empirical formula. Hence: the hotter the day, the lower the drainage and the higher the (ETi) rate. Vice versa, which are one way on the other influenced by weather factors such as temperature, wind etc. The results in this project are quite effective, this techniques grants easy opportunity to estimate water use of tomato and contribute to the development of Agricultural in Nigeria.

5.2 Recommendation

Future experimental work related to this project. The recommendation I proposed are as follow:

i. The calibration and testing of lysimeter should be done before every other thing.

ii. The equipment must be sited at one place (provision of a green house for lysimeter) to avoid obstruction due to fact of moving the instrument or touching it, because obstruction affect readings and enhance falling of flowers and fruits.

iii. The place must be treated regularly to avoid insect infection using ordinary sulfur or any insecticide recommended for that specific plant.

iv. Weeding should be done properly as the need arises.

v. Addition of manure or fertilizer should be done as recommended for a particular plant, to avoid short comings or dyeing of the plant.

vi. The soil must be tilt time to time in order to provided good aeration and enhance infiltration of water in to the soil.

vii. To determine the degree of accuracy of the lysimeter other works must be carried out to compare with metrological method like B.M.N. model.

viii. Irrigators need accurate and timely information on when and how much water to apply, but few farmers in Nigeria have the tools needed to make these irrigation scheduling decision in best way to obtain high yield and crop quality while conserving water, so for that the result of this experiment must be made available to both public and also farmers in the country.

REFERENCES

Abdulelhadi, A.W., Hata, T., Tanakamuru, H., Tada. A and M. A. Taariq.(2000). Estimation of crop water requirements in arid region. Using penman-monteith equation with derived crop coefficient; a case study of Acala cotton in Sudan Gezira irrigated scheme. Agricultural water management, 45(2): 203-214.

Aboukhaled, A., A. Alfaro, and M. Smith. (1982). Lysimeters. FAO Irrigation and drainage paper 39. Food and Agriculture Organization of United Nations. Rome, Italy.

Al-Omran, A.M., Mohammed, F.S., Al-Ghobari, H.M and Alazba A.A. (2004). Determination of evapotranspiration of tomato and squash. Using lysimeters in central Saudi Arabia, international journal for agricultural engineering, 13(1&2): 27-36.

Anadranistakis, M., Liakatas A., Kerkides P., Rizons, S., Gavanosis, j and A. Poulovassilis. (2000). Crop water requirements model tested for crop grown in Greece. Agricultural water Management, 45(3): 297-316.

Allen, R.G., Smith, M., Pruitt, W. O., Pereira, L. S., (1996). Modification of the FAO crop coefficient approach, In: Camp, C.R., Sadler, E.J., Yoder and R.E. (Eds.). Evapotranspiration and Irrigation Scheduling Proceedings of the International Conference, November 3-6 San Antonio, TX, PP.124-132.

Allen, R.G., Smith, M., Pereira, L.S., and Pereira, A. (1994). An update for the calculation of reference evapotranspiration. ICID. Bull. Vol. 43(2): 35-92.

Allen, R. G., L. S. Pereira, D. Raes, and M. Smith. (1998). Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrigation and Drainage paper 56. Food and Agriculture Organization of United Nations. Rome, Italy.

Allen, R.G., I.A. Walter, R.L. Elliott, T.A. Howell, D. Itenfisu, M.E., Jensen, R.L. Snyder, (2005). The ASCE Standardized Reference Evapotranspiration Equation, Am. Soc. Civil Eng., Reston, VA, 59P.

Chalmers, D. J., P. K. Andrews, K. M. Harris, E. A. Cameron, and H. W. Caspari. (1992). Performance of drainage lysimeters for evaluation of water use by Asian pears. Horticultural Science 27: 263–265.

Chow, V. T. (1964). Handbook of Applied hydrology. McGraw-Hill Book Co. New York

Desk dairy. (2011). Niger State, Ministry of Information and communication, Minna.

Doorenbos, J., W.O. Pruitt, (1977). Guidelines for predicting crop water requirements, FAO ONU, Rome, Irrigation and Drainage Paper no. 24 (rev.), 144 pp. Food and Agricultural Organization of United Nations. Rome, Italy.

Egharevba, N.A., (2002). Irrigation and Drainage Engineering Principles, Design and Practices. 1st edition: Nma Printers and publishing co. Ltd, 25A. Shiroro hotel road Minna.

Egharevba, N. A and Mohammed .B. (1999). Evapotranspiration of Selected Cereals in Niger State, Proceeding of the 21st Annual Conference of the Nigeria Society of Engineering, Federal Poly Bauchi, Nigeria PP 76-80

Grattan, S.R., W. George, W. Bowers, A. Dong, R.L. Snyder, J. Carrol, (1998). New crop coefficients estimate water use of vegetables row crops, California Agriculture, 52 (1), 16–20.

Grebet, P., R.H. Cuenca, (1991). History of lysimeter design and effects of environmental disturbances, In: The interpretation of the variation in leaf water potential and stomatal conductance found in canopies, Philos. Trans. R. Soc. London Ser. B., 273, 593–610.

George, S. (2002). Measurement of Consumptive use of Amaranthus Crop. A final year Project report submitted to the Department of Agricultural and Bioresources Engineering, Federal University of Technology, Minna.

Hamdy, A., Lacirignola,D., (1999). Mediterranean Water Resources: Major Challenges toward 21st Century. CIHEAM-IAM Bari ,Italy, P.570.

Howell, T.A., A.D. Schneider, M.E. Jensen, (1991). History of lysimeter design and use for evapotranspiration measurement, in proceeding of International symposium on Lysimetry, July 23-25, 1991, Honolulu, Hawaii, 1-9.

Howell, T.A., J.L. Steiner, A.D. Schneider, S.R. Evett, J.A. Tolk, (1995). Evaporation of irrigated winter wheat, sorghum and corn, ASAE Paper No. 94 2081, ASAE, St. Joseph, MI.

Howell, T. A., A. D. Schneider, D. A. Dusek, T. H. Marek, and J. L.Steiner. (1995). Calibration and scale performance of Bushland-weighing lysimeters. Trans. ASAE 38(4): 1019-1024.

Howell, T. A., Evett, T. A., Schneider, A.D., Dusek, D. A. and Copeland, K. S. (2000). Irrigation fescue grass ET compared with calculated reference grass ET. In process 4th Decennial Natl. Irrig. Symp. 228-242.

Jarvis, P.G., (1976). The interpretation of the variation in leaf water potential and stomatal conductance found in canopies, Philos. Trans. R. Soc. London Ser. B., 273, 593–610.

Katerji, N., G. Rana, (2006). Modelling evapotranspiration of six irrigated crops under Mediterranean climate conditions. Agricultural Forest Meteorological, 138, 142-155.

Katerji, N., G. Rana. (2008). Crop evapotranspiration measurement and estimation in the Mediterranean region, ISBN 978 8 89015 241 2.

Katerji, N., A. Perrier. (1983). A modélisation de l'évapotranspiration réelle d'une parcelled de luzerne: rôle d'un coefficient culltural, Agronomie, 3(6), 513-521 (in French).

Kang, S., B. Gu, T. Du, and J. Zhang. (2003). Crop coefficient and ratio of transpiration to evapotranspiration of winter wheat and maize in a semi humid region. Agricultural water management 59 (1): 239-254.

Kashyap, P. S. and R. K. Panda. (2001). Evaluation of evapotranspiration methods and development of crop coefficients for potato crop in a sub-humid region. Agricultural Water Management 50: 9-25.

Kowal, R. P. and A. H. Kassam. (1976). Yield response to water FAO irrigation and drainage paper 33, FAO Rome.

Larry, G. (1998). Principal of irrigation system design. Inc. Newyork. USA. PP 10-45

Lecina, S., A. Martinez-Cob, P.J. Perez, F.G. Villalobos, J.J. Baselga, (2003). Fixed versus bulk canopy resistence for reference evapotranspiration estimation using the Penman-Monteith equation under semiarid conditions, Agricultural Water Management, 60, 181-198.

Monteith, J. L., (1965): Evaporation and environment. The State and Movement of Water in Living Organisms, 19th Symposium, Soc. Exp. Biol., 205-235.

NPC. (2006). National Population Census report. 2006.

Nigeria Climate: Community Portal.(2011): Annual rainfall of Nigeria along the coast Southern and Northern region. http://www.onlineNigeria.com/links/adv.asp. Accessed on 25th July, 2011.

Orgaz, F., M.D. Fernandez, S. Bonachela, M. Gallardo, E. Fereres, (2005). Evapotranspiration of horticultural crops in an unheated plastic greenhouse, Agricultural Water Management, 72, 81-96.

Pruitt, W. O., and Angus, D. E.(1960). Large weighing lysimeter for measuring evapotranspiration. Rans ASAE.3(2): 13-15,18.

Rana, G., N. Katerji, (2000) Measurement and estimation of actual evapotranspiration in the filed under Mediterranean climate: a review, European Journal Agronomy, 13(2-3), 125-153.

Schneider, M.E. Jensen, (1991). History of lysimeter design and use for evapotranspiration measurement, In R.G. Allen, T.A. Howell, W.O. Pruitt, I.A. Walter, M.E. Jensen, Proceeding of International symposium on Lysimetry, July 23-25, 1991, Honolulu, Hawaii, 1-9.

Stanhill, G. (1973). Evaporation, transpiration and evapotranspiration: a case for Ockham's razor. In: Physical aspects of soil water and salts in ecosystems, 207-220. A. Hadas, ed. New York: Springer-Verlag.

Shideed, K., T. Oweis, M. Gabr., M. Osman, (1995). Assessing on-farm water use efficiency: a new approach, ICARDA/ESCWA, Ed. Aleppo, Syria, 86 pp.

Todorovic, M.., (1999). Single-layer evapotranspiration model with variable canopy resistance, Journal of Irrigation and Drainage Engineering., 125 (5), 235–245.

Tyagi, N. K., D. K. Sharma, and S. K. Luthra.(2000). Evapotranspiration and crop coefficients of wheat and sorghum. Journal of Irrigation and Drainage Engineering 126 (4): 215-222.

Yang, J., B. Li and S.Liu. (2000). A large weighing lysimeter for evapotranspiration and soil water and groundwater exchange studies. Hydrological Processes. 14:1887-1897.

APPENDIX F_1: Daily Wind Velocity of Minna, Nigeria [2011]

January	February	March	April	May	June	July	August	September
5	5	4	3	4	7	4	7	7
6	4	6	4	3	4	4	5	4
6	6	6	4	3	4	8	6	5
6	5	5	4	3	3	4	4	3
5	5	5	6	3	7	3	5	5
4	6	4	4	4	9	3	6	9
3	5	4	4	5	8	4	4	8
4	5	4	3	3	3	3	4	3
4	4	5	4	4	4	3	4	4
3	5	4	6	4	5	4	5	5
3	3	5	5	5	4	4	4	4
4	4	5	5	6	5	4	5	5
4	5	6	4	4	3	3	3	4
4	4	5	4	4	3	3	5	3
5	4	5	5	4	7	3	5	7
4	4	4	6	5	5	3	4	4
4	5	4	4	3	5	3	3	5
4	4	3	4	4	3	5	5	4
3	5	3	4	9	5	5	4	4

4	4	4	3	5	3	4	3	4
4	9	3	5	6	5	3	5	5
4	4	3	7	4	4	3	4	4
5	4	4	4	4	3	4	5	3
4	5	4	4	7	4	3	5	4
4	4	4	4	5	3	4	4	3
4	4	4	8	4	6	3	5	4
4	5	4	4	6	3	4	5	5
4	4	4	4	7	6	3	4	5
6	-	4	3	3	7	4	5	4
4	-	3	4	3	3	3	4	5
5	-	3	-	4	-	3	5	4

APPENDIX F_2: Mean Daily Temperature of Minna, Nigeria [2011].

January	February	March	April	May	June	July	August	September
27	29.5	31.5	31.5	31.5	24	25.5	27.5	25
26	31	32	33.5	32	26	27	27	26
27.5	30.5	32.5	32	32	28	23.5	29.5	30
27.5	31	31.5	32	32	27.5	26	30	29
26	30	32	32.5	31.5	28.5	27	29	29.5
26.5	30	31	29	32	27	27	29	27.5
26	31	32	32	32.5	28	25.5	26.5	28.5
27.5	30.5	33	34	33	26	26.5	24.5	27.5
26.5	29.5	33	33	33	28.5	25.5	27.5	30
27	31	31	32	33	27.5	26	29	26.5
27.5	29.5	33	31	33	26	30.5	26.5	31
28.5	30	32.5	29.5	32	28.5	26.5	29	25
29	30.5	32.5	31	31.5	26	26	26	28
29	31.5	31.5	31.5	32	28.5	27	30.5	26.5
29	30	32	30.5	33	27.5	28	24	29.5
29	31.5	31	32	30	26.5	26	26	31
30	31.5	31.5	32	28	28	26.5	25	27
28.5	32.5	33.5	31.5	31	25.5	25.5	28	26.5
30	33	34.5	29.5	29	28	25	23.5	29
29.5	31	33	30	29	26	26.5	26	28.5

29	32.5	33	31.5	31.5	26	26	25	28.5
29	31.5	32.5	32.5	31	26	26	25	25
29	32	32.5	30	29.5	27.5	26.5	30	29
27.5	30	32	31	30	24.5	26.5	29	28.5
29	32.5	35.5	31.5	28	27	27.5	25.5	28.5
28	33	33	31.5	27.5	27	25	30	29
27.5	32.5	33.5	29.5	28	27	27	25.5	26.5
29.5	32	32	32	26	27	26.5	24	25.5
28	-	32.5	32.5	25.5	25	27.5	28.5	27
27.5	-	32	32	28.5	26	27.5	29	26
29.5	-	32.5	-	29.5	-	26	27	27

ENDIXF$_3$: Daily Temperature of Minna, Nigeria [2011].

uary ax, in	February Tmax, Tmin	March Tmax, Tmin	April Tmax, Tmin	May Tmax, Tmin	June Tmax, Tmin	July Tmax, Tmin	August Tmax, Tmin
20	37,22	36,27	40,23	26,22	30,21	30,25	28,22
19	39,23	39,25	40,24	31,21	30,24	31,23	30,28
21	39,22	39,25	39,26	32,24	28,19	32,27	31,29
20	38,24	39,25	39,24	32,23	30,22	31,29	32,26
19	38,22	38,25	39,25	33,24	31,23	30,28	30,25
18	37,23	37,27	37,25	31,23	31,23	30,28	29,26
17	40,22	38,27	38,28	31,25	28,23	28,25	31,26
19	40,21	40,26	39,27	30,22	30,23	28,21	30,25
18	37,22	38,28	39,27	33,24	29,22	29,26	32,28
18	39,23	38,28	38,24	31,24	30,22	30,28	29,24
20	37,22	38,28	39,27	29,23	39,22	29,24	33,29
22	37,23	38,26	39,26	32,25	30,23	31,27	28,22
,23	37,24	38,25	38,27	30,22	29,23	28,24	30,26
,22	38,25	37,27	38,25	33,24	31,23	32,29	29,24
,21	36,24	38,28	38,26	33,22	32,24	27,21	31,28
,23	39,24	36,24	38,24	31,22	30,22	30,22	33,29
,24	36,27	32,24	39,24	31,25	30,23	27,23	28,26
,22	39,26	36,26	40,27	30,21	27,24	31,27	29,24

23	40,26	35,23	42,27	31,25	28,22	32,25	30,28
23	37,25	33,25	39,27	31,21	30,23	28,24	31,26
21	38,27	37,26	30,27	29,23	30,22	29,21	33,24
24	38,25	35,27	38,27	30,22	29,23	28,22	29,21
23	39,25	34,25	38,27	31,24	30,23	31,29	30,28
20	40,20	36,24	38,26	27,22	30,23	30,28	31,26
22	37,28	34,22	42,29	31,23	32,23	29,22	32,25
20	39,27	30,25	39,27	29,22	28,22	31,29	31,27
19	39,26	34,22	39,28	32,22	31,23	28,23	28,25
23	40,24	30,22	38,26	32,24	29,24	27,21	29,22
22	-,-	29,22	40,25	29,21	32,23	33,24	31,23
20	-,-	33,24	39,25	29,23	31,24	30,28	30,22
22	-,-	33,26	40,25	-,-	28,24	29,25	-,-

APPENDIX F_4: Mean Monthly Sunshine Radiation and Radiation Factor of Minna, Nigeria [2010].

Month	Sunshine Radiation	Radiation Factor
January	7.3	0.0914
February	7.7	0.09634
March	6.8	0.0851
April	7.3	0.0914
May	7.1	0.0888
June	6.8	0.0851
JULY	4.9	0.0661
August	4.6	0.0575
September	5.5	0.0688
October	6.4	0.0801
November	8.9	0.1114
December	7.1	0.088

APPENDIX F_5: Mean Monthly Relative Humidity Minna, Nigeria [2002-2010].

Months	Mean-Minimum R.H (%)	Mean-Maximum R.H (%)
January	20.03	59.06
February	15.5	51.37
March	18.37	66.87
April	29.5	84.12
May	54.25	91.25
June	65.75	93.75
July	71.37	96.38
August	75.62	96.5
September	75.35	87.5
October	60.9	96.5
November	34.5	75.5
December	23	70

Source: Meteorological data are collected from Minna Airport (Maikunkele local government)